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C4I2 IN SPACE:

SOLVING THE SATCOM SHORTFALL

Submitted to

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C4I2 IN SPACE
Solving the SatCom Shortfall

Without a coordinated team-effort, an army can not hope for control on the battlefield. Without effective communication, a commander can not hope for effective command and control of his army. In today's highly-centralized, global command network, standard terrestrial communications alone are insufficient. Satellite communication is indispensable for command and control on today's battlefield, but requirements for SatCom far outstrip available resources. To exacerbate this problem, demand for reliable, long-haul, high-quality communication continues to grow geometrically.

Satellites offer many well-known advantages for C4I2 in battlefield operations. These advantages include long range, freedom from obstructions, high quality, and increased interoperability.

Satellite transmission allows units to communicate reliably over long distances. The range depends on the orbital position and technical characteristics of the satellite, but signals are routinely transmitted several thousand miles. HF Radio has well known long-distance capability as well, but unlike satellite communication, it is highly dependent on atmospheric conditions. Higher frequencies and sophisticated electronics make satellite communication less susceptible (although not immune) to the whims of nature.

Most terrestrial radios using frequencies above the HF range are severely hampered by obstructions between transmitter and receiver. Even if the transmitter and receiver

are relatively close to each other, a significant terrain obstacle between them can disrupt communication. Satellites however, provide communication relatively unaffected by terrain. Since signals go through a transponder in geosyncronous orbit, terrain features are not in the path of the signal. Of course, this freedom from terrain obstacles is maximized when the orbit of the satellite places it "high" in the sky relative to the terminal. Low orbital inclinations with respect to the terminal (as when at high latitudes) diminishes this advantage--especially in rough terrain.

In addition to providing freedom from terrain obstacles, satellites provide high-quality communication paths and are relatively immune to atmospheric changes. Satellites also provide much greater throughput (both in speed and in bandwidth) because of their high frequencies, low error rates, and sophisticated circuitry.

Because of these advantages, our need for satellite links far exceeds the capacity of our current military satellites. Our paper will discuss the current state of satellite communication (SatCom) technology, its employment, and the growing shortfall. We will go on to offer suggestions for correcting the SatCom shortfall.

Several possibilities exist for filling the SatCom gap. These include more efficient use of existing military and commercial satellites, higher user densities, surrogate satellites, the expansion of HF radio, and emerging telecommunications technologies such as meteor burst communications

(MBC) and fiber-optics.

In order to better understand the suggestions for solving the SatCom shortfall, we will briefly present each of the current satellite systems' capabilities and shortcomings. We will then discuss current demands on military satellites and problems in allocating available resources. We will use a notional joint task force as a framework for our discussion. Armed with a working knowledge of current satellites and the dilemma our planners face in their proper allocation, the reader can fairly evaluate our proposals.

SATELLITES TODAY

Satellite communication is widely used by U.S. armed forces in situations ranging from a single-service, low-intensity operation to joint, high-intensity conflicts. Demand for satellite communication exceeds availability, and the demand is expected to increase.

Current satellite communication falls into two general categories. Ultra-high frequency (UHF) comprises the first category, while super-high frequency (SHF) and extremely high frequency (EHF) make up the second. The main satellite systems which operate within these categories are listed in Table I.

Table I -- Major Military Satellite Systems

FLTSATCOM	UHF
LEASAT	UHF
UFO	UHF
DSCS	SHF
MILSTAR	EHF
LIGHTSAT	EHF

FLTSATCOM/LEASAT

FLTSATCOM satellites (Figure 1) are in orbit near the equator at 100 degrees W, 23 degrees W, 172 degrees E, and 72 degrees E. Each spacecraft can relay 23 radio channels in the ultra-high frequency (UHF) and super-high frequency (SHF) range. The Navy is assigned ten 25 KHz channels. The remaining 13 channels are actually part of the AFSATCOM program. To preclude interference from adjacent satellites, each FTLSATCOM satellite has three different frequency plans (see Table II) for its channels. Each spacecraft has a life expectancy of five years but can be kept in orbit for as long as seven to twelve years by careful use of on-board station-keeping fuel.

In 1978 the Navy contracted with Hughes Corporation for a leased satellite system, LEASAT. LEASAT spacecraft (Figure 2) are launched by space shuttle and placed in geosynchronous orbit over the Atlantic, Pacific, and Indian Oceans. LEASAT has 13 radio channels; seven are 25-KHz, five are 5-KHz, and one is 500-KHz. Six 25-KHz channels are direct relay, each with a separate transponder. A channel management technique called Demand Assigned Multiple Access (DAMA) allows LEASAT to make effective use of its six channels (four less than FLTSATCOM.)

DAMA allows several users to share a channel. Thus each person is placing demands on the channel only when he is actually transmitting. The demand on the system may be distributed through either frequency division multiple access (FDMA) or time division multiple access (TDMA) schemes.

FLTSATCOM SATELLITE

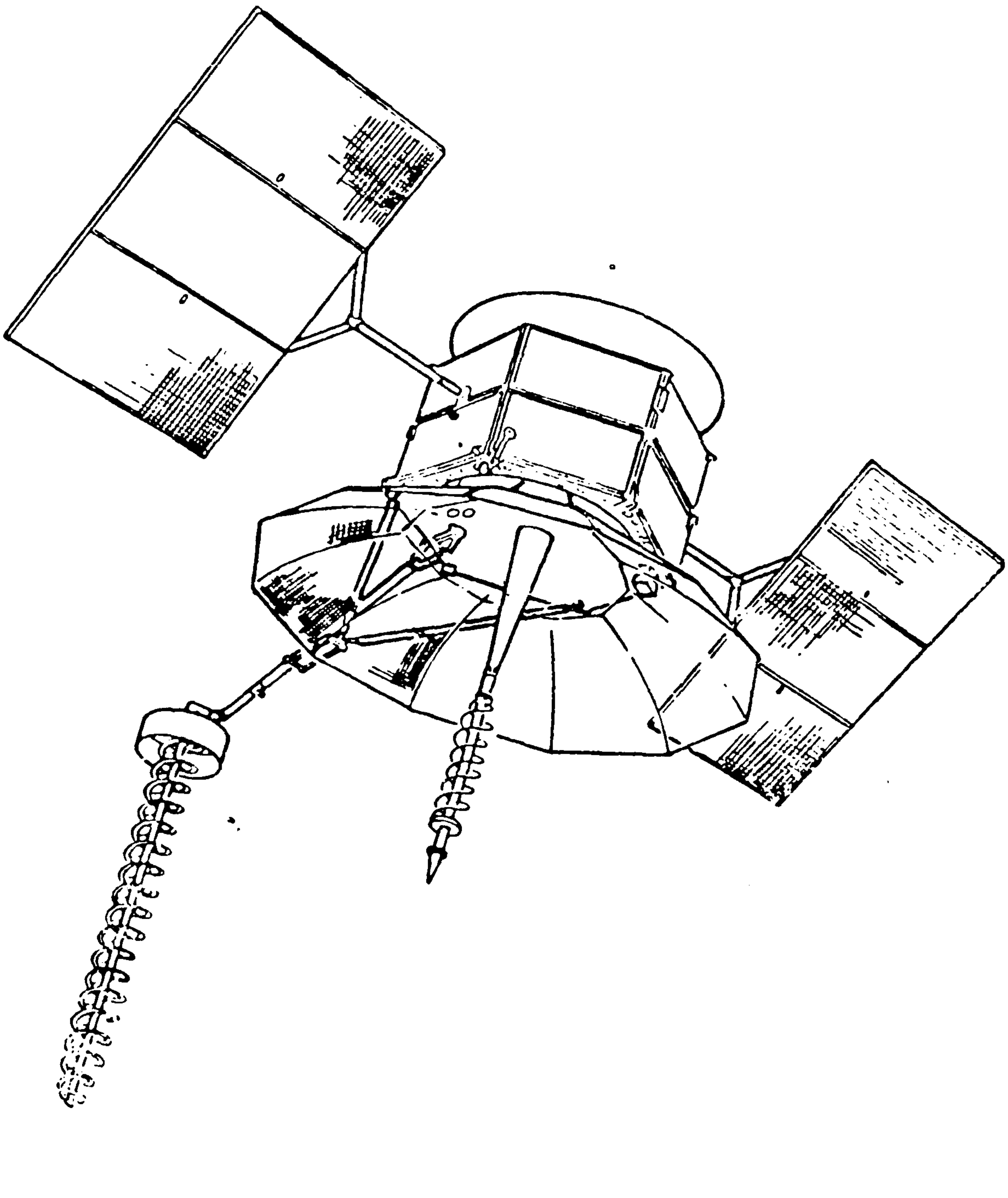


FIGURE 1

TABLE II

FLTSATCOM RECEIVE AND TRANSMIT FREQUENCIES

Channel	Plan	Downlink Freq (MHz)	Uplink Freq (MHz)	Nominal Bandwidth (kHz)
1	A	250.45	shf	25
	B	250.55	shf	25
	C	250.65	shf	25
2	A	251.95	292.95	25
	B	252.05	293.05	25
	C	252.15	293.15	25
3	A	252.65	294.65	25
	B	253.75	294.75	25
	C	253.85	295.85	25
4	A	255.35	296.35	25
	B	255.45	296.45	25
	C	255.55	296.55	25
5	A	256.95	297.55	25
	B	257.05	298.05	25
	C	257.15	298.15	25
6	A	258.45	299.45	25
	B	258.55	299.55	25
	C	258.65	299.65	25
7	A	265.35	306.35	25
	B	265.45	306.45	25
	C	265.55	306.55	25
8	A	266.85	307.85	25
	B	266.95	307.95	25
	C	267.05	308.05	25
9	A	268.25	309.25	25
	B	268.35	309.35	25
	C	268.45	309.45	25
10	A	269.75	310.75	25
	B	269.85	310.85	25
	C	269.95	310.95	25
11	A	243.945	317.045	5
	B	244.045	317.145	5
	C	244.145	317.245	5
12	A	243.955	317.055	5
	B	244.055	317.155	5
	C	244.155	317.255	5
13	A	243.960	317.060	5
	B	244.060	317.160	5
	C	244.160	317.260	5
14	A	243.965	317.065	5
	B	244.065	317.165	5
	C	244.165	317.265	5
15	A	243.970	317.070	5
	B	244.070	317.170	5
	C	244.170	317.270	5
16	A	243.975	317.075	5
	B	244.075	317.175	5
	C	244.175	317.275	5
17	A	243.990	317.080	5
	B	244.080	317.180	5
	C	244.180	317.280	5
18	A	243.385	317.085	5
	B	244.085	317.185	5
	C	244.185	317.285	5
19	A	243.990	317.090	5
	B	244.090	317.190	5
	C	244.190	317.290	5
20	A	243.995	317.095	5
	B	244.095	317.195	5
	C	244.135	317.295	5
21	A	244.000	317.100	5
	B	244.100	317.200	5
	C	244.200	317.300	5
22	A	244.010	317.110	5
	B	244.110	317.210	5
	C	244.210	317.310	5
23	A	260.600	294.200	500
	B	261.700	295.300	500
	C	262.300	295.900	500

LEASAT SATELLITE

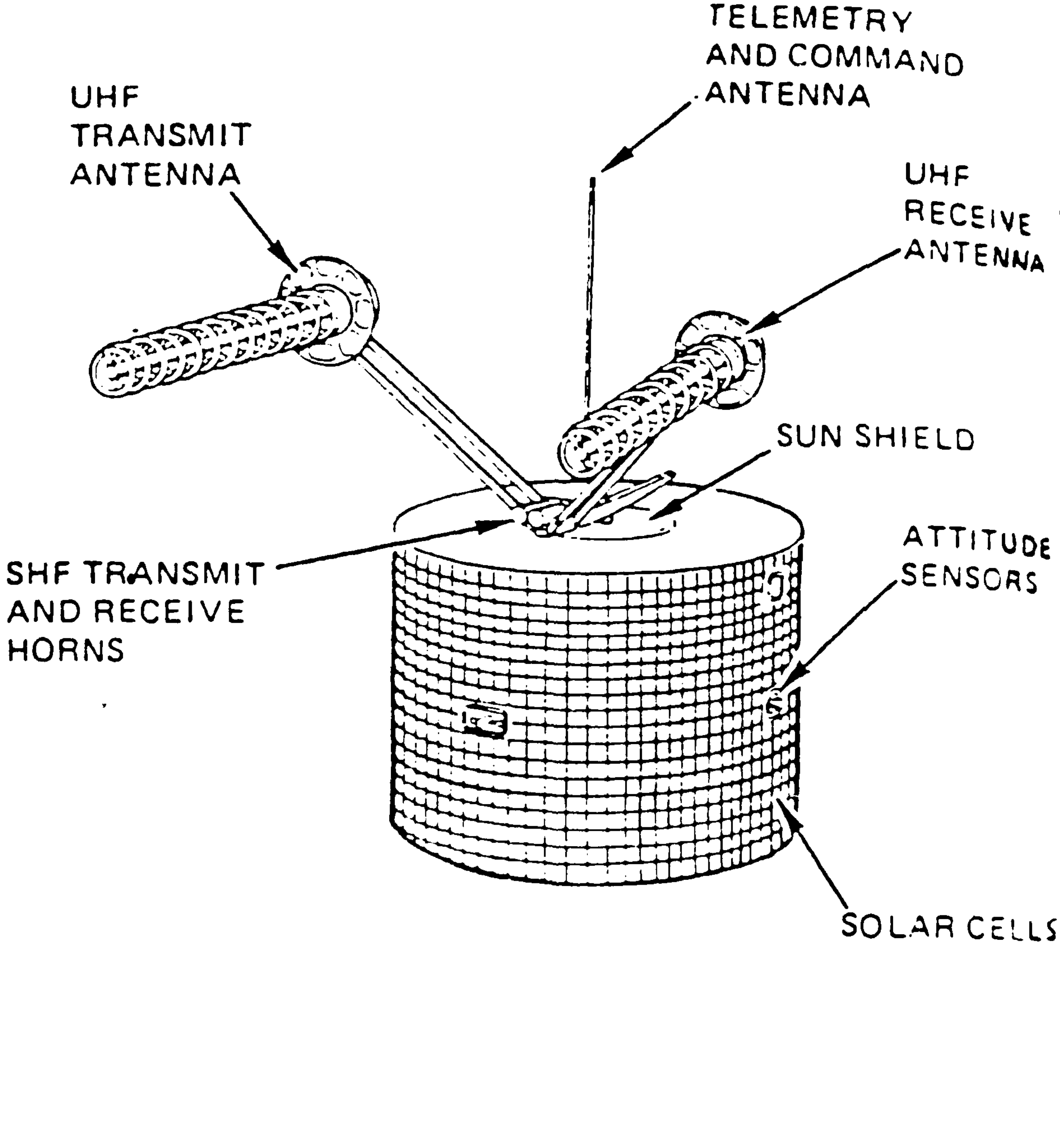


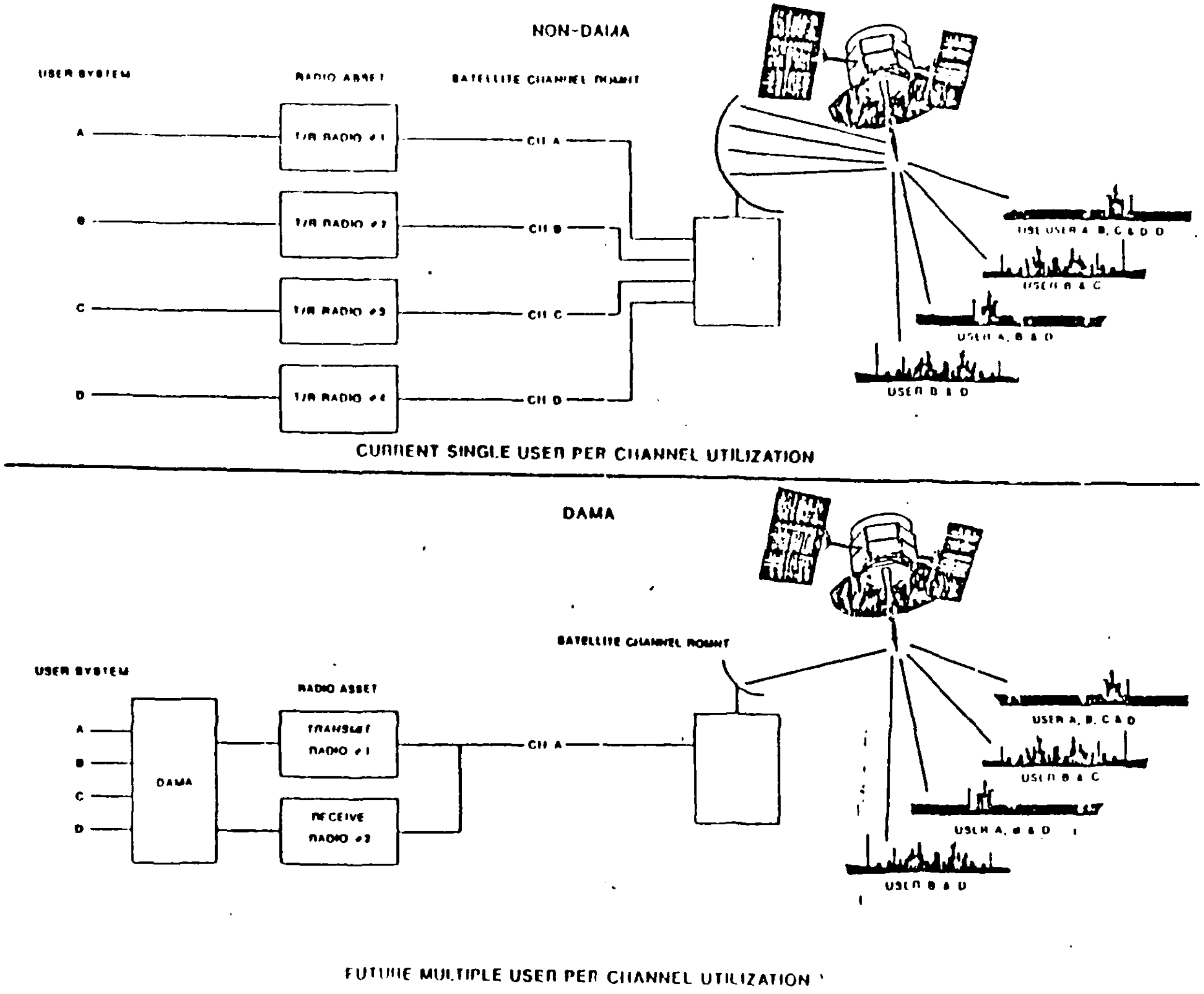
FIGURE 2

Figure 3 illustrates a comparison between DAMA satellite channel usage and non-DAMA usage. By allowing multiple users to share a channel, DAMA allows more users access to the system and is therefor more cost efficient. Occasionally a user will receive a "busy signal" if there is too much demand on the system.

FLTSAT and LEASAT operate at relatively low data rates (75 baud, 2.4 Kbps, and 16 Kbps). This slow data speed greatly limits the number of system users as well as lengthens data transmission times. The second limiting factor of FLTSAT and LEASAT is the susceptibility of the systems to electronic counter measures. They are easily located by direction-finding techniques and can be jammed using unsophisticated equipment. Unlike more modern satellites, they have no anti-jam or nulling capability.

UHF FOLLOW ON (UFO)

The UFO system will offer 68 channels or three times the capacity of current UHF systems. It will offer a low data rate (75 baud or 2.4 Kbps). Improvements will include SHF and EHF capability and a 10-year life expectancy. However, it will still have the same low through-put problems of LEASAT/FLTSAT and will support a very limited number of users per channel.



Non-DAMA/DAMA Satellite Utilization

DSCS

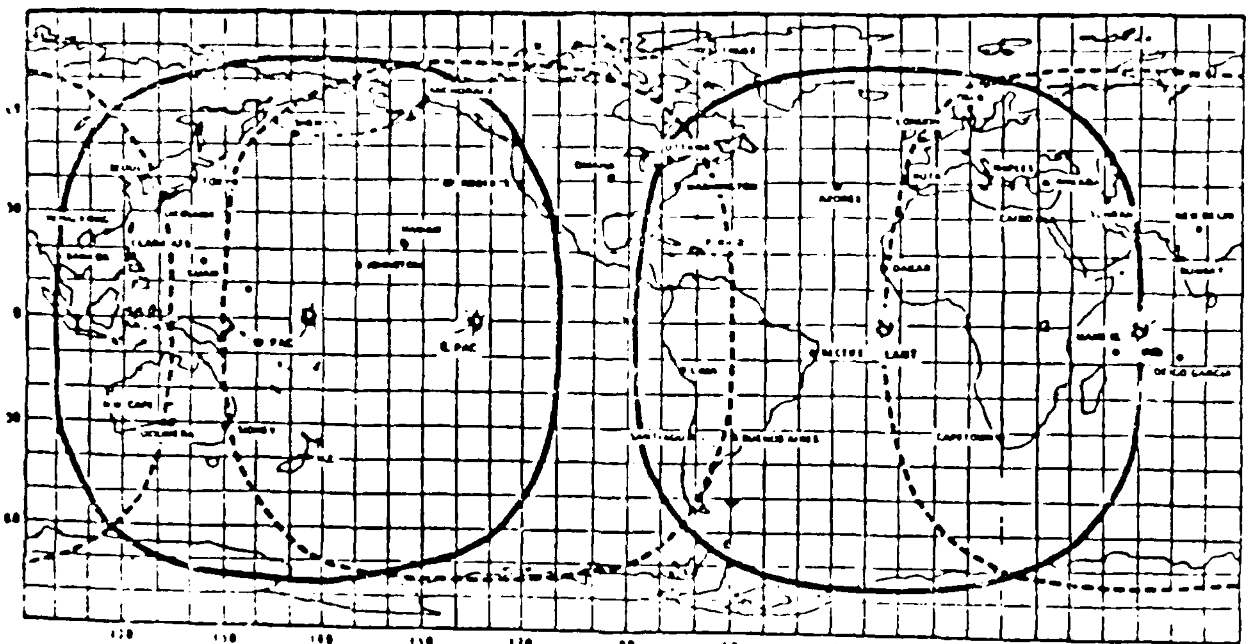
The Defense Satellite Communications System (DSCS) was designed for use by the Army, Navy, Air Force, Marines, and other NATO military forces. DSCS is supposedly acheives continuous global coverage with four satellites. Although this is technically true, communications capability is marginal at the edge of each satellite's foot print, especially at the higher latitudes. The main reason for this problem is that the satellites are in geostationary orbits. The longitudes of the nine DCSC satellites follow in Table III.

Table III. DSCS Satellite Locations

East Atlantic	12 degrees West
East Pacific	135 degrees West
West Pacific	175 degrees East
Indian Ocean	60 degrees East
Indian Ocean Reserve	66 degrees West
West Atlantic	52.5 degrees West
East Atlantic Reserve	15 degrees West
East Pacific Reserve	130 degrees West
West Pacific Reserve	180 degrees West

Notice in Figure 4 that the foot prints of the five primary satellites overlap, but that none have coverage near the poles.

Characteristics of the DSCS system (Figures 5 and 6) are summarized in Table IV. The DSCS III satellites have important improvements over the older DSCS II satellites, which are being gradually replaced. The newer DSCS III satellites have two more channels (six total), a longer life expectancy (10 years), increased orbital stability, better anti-jam capability, and higher power transponders.



Earth Coverage of Geostationary DSCS Satellites

DCSC II SATELLITE

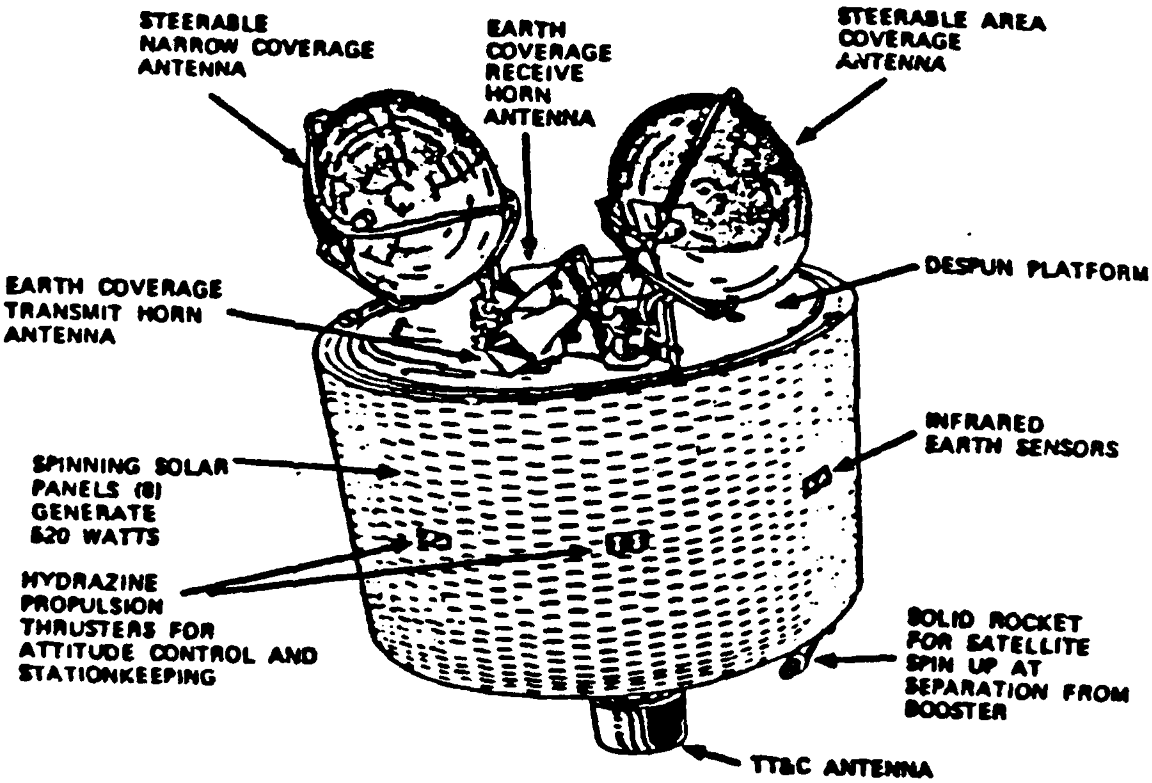


FIGURE 5

DSCS III SATELLITE

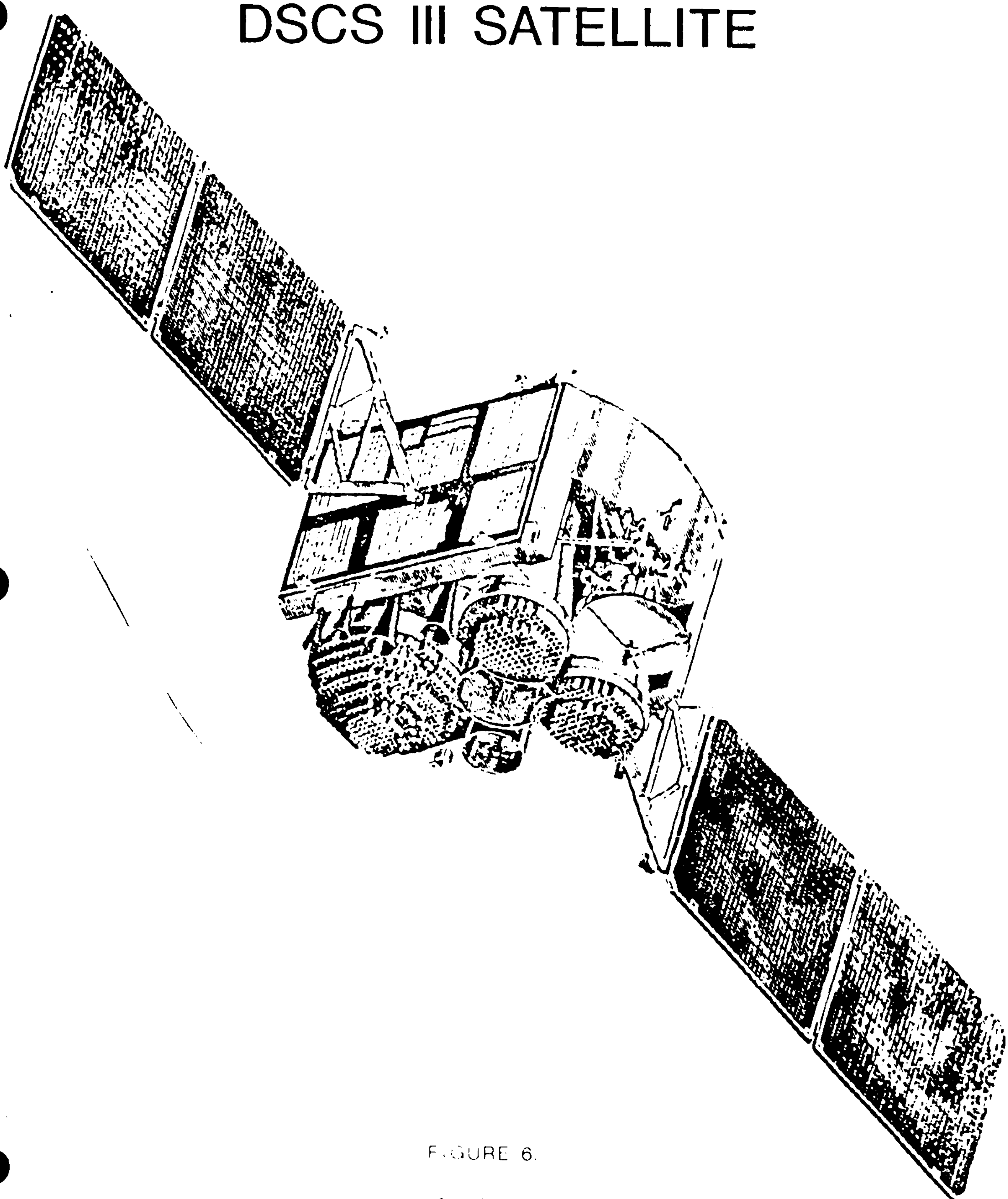


FIGURE 6.

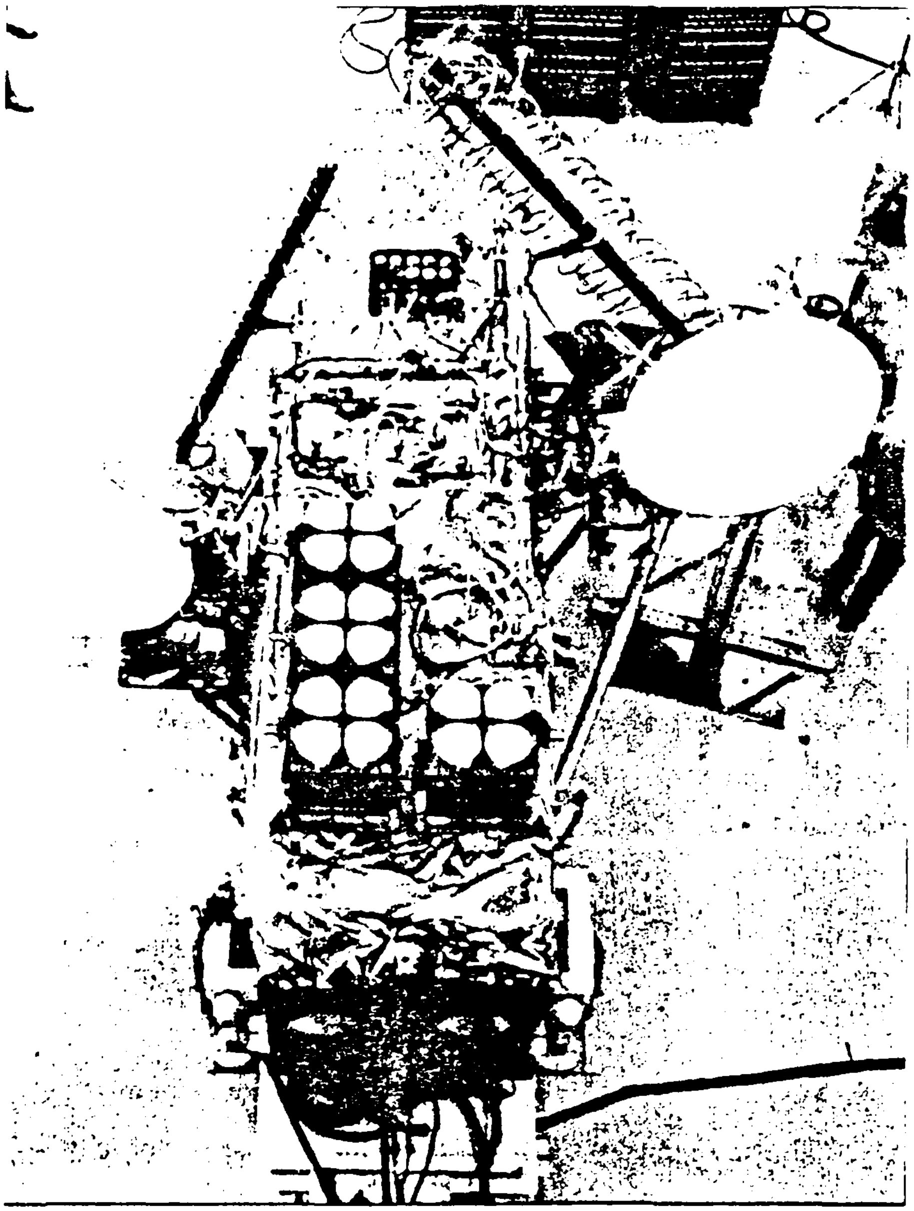
With the transition to DSCS III, the DSCS system is projected to last at least ten more years even though the oldest DSCS III satellite is already nine years old. Users of DSCS II have complained of difficulty in maintaining synchronization. The increased orbital stability of DSCS III has greatly enhanced the reliability of communications.

MILSTAR

Another satellite system being developed by the U.S. Air Force is MILSTAR (Military Strategic Tactical and Relay). MILSTAR (Figure 7) was designed as a tactical EHF system for use by all branches of the service. It will incorporate the most recent satellite technology including antijamming scintillation, low probability of intercept or detection, spread-spectrum signal processing, and pencil-beam transmission. Using FDMA for the uplink and TDMA for the downlink, MILSTAR is a very complex system. Unlike other systems, channel capacity is not firmly defined. However, it is generally accepted that 192 voice users at 2.4 Kbps will exhaust a MILSTAR satellite's capacity (3).

Although MILSTAR is designed for interoperability, each service is developing their own ground-based terminals. The Army has developed the AN/TSC-124 for special communications needs in Europe, Korea, and world-wide special and joint operations. The Navy is designing terminal equipment through its Navy EHF Satellite Program (NESP), and the Air Force has been developing their Ground Command Post Terminal (GCPT).

MILSTAR SATELLITE



USAF/Lockheed MILSTAR satellite

FIGURE 7

The significant difference between MILSTAR and other satellite systems is MILSTAR's use of the EHF frequency spectrum (20 to 44 GHz). Even though this new set of frequencies is lightly used, only 192 voice channels are possible with MILSTAR. Another problem is the system's low throughput. MILSTAR is envisioned as a low data rate system having traded high volume for the security of spread-spectrum transmission. However, a possible modification could be added to upgrade some circuits to 300 Kbps.

Another major capability includes MILSTAR's on-board processing and switching which will allow inter-satellite cross-links. The system will be able to relay signals through multiple satellites, eliminating ground-based relays. The system will provide true global coverage using geostationary as well as inclined orbits. When fully deployed--around 1995--MILSTAR will have seven satellites in orbit at all times with two or more as spares.

No MILSTAR satellites have yet been launched; MILSTAR's biggest problem during development and fielding continues to be its high cost.

LIGHTSAT

One outgrowth of MILSTAR's technological advances has been the development of lightweight EHF satellites known as LightSat. LightSat systems (Figure 8) are intended to be lightweight, inexpensive alternatives to MILSTAR. It was thought that the smaller, 280-pound satellites could be launched as needed for crisis situations and increased communication needs during time of war.

These advantages are largely outweighed by the program's rising costs and the satellites' short lifespan--only three years compared to the ten years projected for MILSTAR. Its lower orbit and decreased capabilities (relative to MILSTAR) would require a constellation of 240 satellites for full global coverage. The result is that LightSat, MILSTAR's competition, is still a system of the future.

Table IV summarizes the characteristics of several satellite systems and some of their individual problems and limitations.

LIGHTSAT SATELLITE

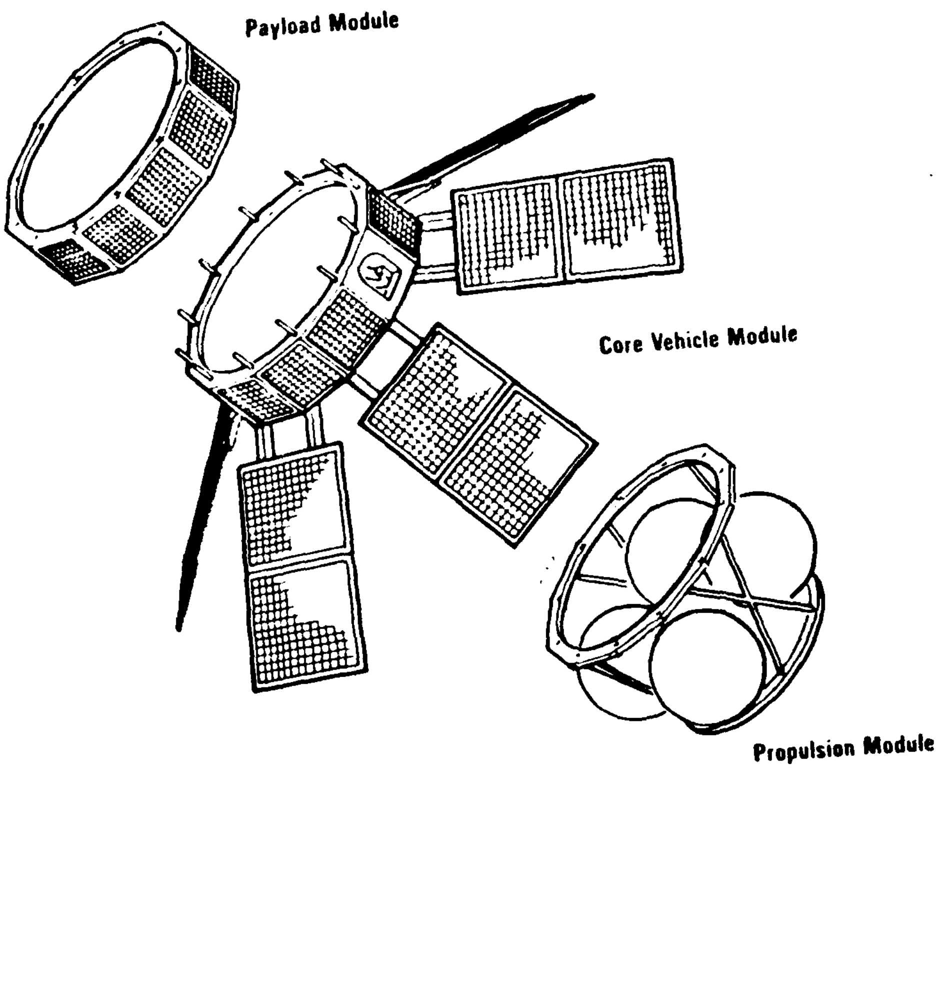


Table IV. Satellite Characteristics and problems.

SATELLITE TYPE	DSCS	MILSTAR	FLTSAT	LEASAT	UFO
CHANNELS	III-6CH II-4CH	N/A	(22) 25 KHz (1) 500 KHz	(5) 5 KHz (7) 25 KHz	(26) 25 KHz (42) 5 KHz
USERS/CHANNEL	55/CH (THEORY 216/CH)	192 Users	21 (500 KHz) 1 ea on 25 KHz		TBD
DATA RATE	100 Mbps	2.4 Kbps (Potential 300 Kbps)	75 BAUD 2.4 Kbps 16 Kbps	SAME AS FLTSAT	75 BAUD 2.4 Kbps
FREQ	SHF	EHF	UHF SHF (FLT BROAD) 2 EHF	UHF	UHF SHF 4-9 EHF
# IN CONSTELL-ATION	III (4) II 4	9	6	4	16
CRYPTO	YES	YES	NO	NO	
COST	$150M	$1 BIL	$60M		
AGE	III 9 Yr II 10+ Yr	N/A	2-7 Yr	1-5 Yr	N/A
LIFE EXPECT	III 10 Yr II 5 Yr	10 Yr	5 Yr	7 Yr	10 Yr
PROBLEMS	III 1,5 II 1,2,3	4,5,6,8	1,3,6,7,8	1,6,7,8	4,6,8

PROBLEMS:

1. Poor coverage at higher latitudes--none at the poles.
2. Poor orbital stability.
3. Aging system. System has exceeded life expectancy.
4. System not operational at this time.
5. High cost of satellite.
6. Limited users per channel.
7. Susceptible to jamming and DF.
8. Low through-put.

EMPLOYING SATCOM TODAY

In order to solve the shortfall in SatCom it is important to know how satellites are employed today. In the following section we seek to show both how satellites are used for battlefield C3 and the difficulties experienced in the employment of SatCom.

Tactical satellite communication has experienced an explosion in increasing requirements since the introduction of portable and transportable terminal equipment to the tactical armed forces. The advantages of satellite communication over conventional, lower spectrum radios are especially attractive to forces that are likely to be engaged in a fluid, fast-moving tactical environment or whose area of operation is not likely to be in the proximity of a major communications facility (22).

Generally speaking, UHF satellite communication is characterized by tactical, single-channel terminal equipment primarily used for intra-theater communications for voice and low to medium speed data transmission. SHF satellite communication, because of the requirement for far greater power and more extensive ground terminal equipment, is used primarily for high speed and/or high volume data transfer and telephone switching networks.

A notable exception is the dependence of the U. S. Navy on UHF links for shipboard satellite communications. Restrictions on available space on ships and the technical difficulties ship-board terminal antennas have in tracking SHF satellites while the ship is moving dictate this depen-

dence. The Navy adopted the multiplexing of 25-KHz UHF channels as a partial solution for increased satellite communications requirements, but high-speed data transfer capability is still not generally available aboard ship. The Navy is addressing its need for SHF satellite communications through its WSC-6 program and is presently installing Air Force SHF satellite terminal equipment on-board selected ships as an interim measure (18).

Despite this interim attempt to incorporate SHF communication, the problems cited above persist. The Navy still has difficulty accommodating the size, power requirements, and cost of current SHF terminals. However, the biggest hold-up in widening the use of SHF continues to be the problem of tracking SHF satellites while at sea.

Table V lists the major users of satellite communications, divided into SHF multichannel systems, and UHF systems (8:i,9:i).

Table IV. Major SatCom Users

SHF/UHF	UHF Only
CINC Central Command	CINC Forces Command
CINC European Command	U.S. Coast Guard
CINC Atlantic Command	Defense Intelligence Agency
CINC Pacific Command	
CINC Strategic Air Command	
CINC Southern Command	
CINC Special Operations Cmd	**SHF Only**
CINC Space Command	
CINC Transportation Cmd	U.S. State Department
Joint Chiefs of Staff	Defense Communications Agency
U.S. Army	
U.S. Navy	
U.S. Air Force	
U.S. Marine Corps	
White House Communications	

Current military doctrine mandates the employment of our armed forces in joint task forces (JTFs). The single most important factor in determining the JTF's requirements for satellite communications is host-nation support and the host country's in-place communications infrastructure (4). This importance is dramatized by the satellite network put in place in Saudi Arabia for Operation Desert Shield/Storm. This system is larger than any other theater network to date--even larger than the network planned for the European theater in the event of a full-scale Soviet assault. The sheer size of the military forces arrayed against Iraq and the scope of their mission dictated an extensive satellite network. However, the enormity of the satellite communication network in Saudi Arabia was due to the necessity for SatCom to serve as the primary, backbone system for in-theater operations. Despite full cooperation by the host nation, the primitive communications system in the area of operation and the desert geography itself* forced the allies to depend on satellites as the primary means for both voice and data connectivity.

A comparison can be made to the Korean theater of operations. The probable American military response to North Korean aggression bears many similarities to the action in Southwest Asia, including the size of the forces involved. South Korea would similarly give extensive cooperation to an allied force defending Korean soil. Unlike in Saudi Arabia, the United States has maintained an extensive military

* Radio surface-waves propagate very poorly over dry sand--an electrical insulator.

presence in South Korea for decades. This relationship and Korea's industrial development have greatly benefited the communications infrastructure.

The United States, in conjunction with South Korea, has built an extensive tactical communications network using land-lines, radio, and satellite links. Several of South Korea's communications facilities are gateways to larger, world-wide communications systems. South Korea itself enjoys an extensive, rapidly developing civilian communications system, much of which can be adapted to military use in time of war. (5:K-1-2) With this infrastructure, a South Korean conflict would require far less tactical satellite support to prosecute military operations than did Desert Storm. The need for tactical, single-channel satellite communications would be comparable to the needs of similar maneuver elements in Southwest Asia, but the need to install a huge SHF network would not be nearly so critical in South Korea.

On the other end of the spectrum from the mission of large-scale, conventional warfare are special operations. In recent years, special operations forces' requirements for satellite communications (especially single channel, UHF links) have risen dramatically. The mission of special operations forces depends on speed and coordination. Special operations teams would normally operate as small, vulnerable, remote groups. The equipment they use must be portable or highly transportable. Small, single-channel UHF satellite communications terminal equipment is ideal, given

their mission and combat environment. Although special operations forces require far less in-theater SatCom as a whole than large conventional forces, special operations' per-unit requirements are likely to be the heaviest of any tactical organization (4, 18). Since UHF satellites are already full to capacity, rising special operations needs will either force other users to use non-satellite communication or the special operations users themselves will be forced off the satellites.

Implicit in the definition of a task force is its employment overseas, and such a task force (particularly one with a land or amphibious component) can be generally characterized (25). The Joint Connectivity Handbook lists the functional areas requiring connectivity in such a joint task force as land combat operations, intelligence, air operations, maritime operations, fire support and combat service support.

A joint task force operating with components of all four services will have roughly one quarter of all its communications links depend totally or in part on satellites (22, 25).

Because of the expeditionary missions of the notional JTF, it would be fair to define its critical communications links as those that connect it with higher authority and those that allow it access to national systems and agencies. Thus defined, its critical links to higher authority would be connectivity to WWMMCS, links to the White House Communications Agency (WHCA), the National Military Command Center

(NMCC), and the links to appropriate unified or specified command headquarters. The JTF's connectivity to national systems and agencies would be installed through a gateway entry into Defense Communications Agency networks such as AUTODIN and the Defense Data Network for record traffic, AUTOVON and AUTOSEVOCOM for military telephone switching networks. Normally, all such links would be multichannel satellite (SHF) links--the exception previously stated being Naval ships (25).

The advantages of satellite communication have predictably led to a condition where demand greatly exceeds available satellite capacity. The problems are most acute in the UHF single-channel arena. The transition of the Navy into the less crowded SHF multichannel spectrum will alleviate the problem somewhat. However, moving the Navy to SHF SatCom will only significantly alleviate UHF satellite congestion if all Navy combattant ships are able to communicate through SHF satellites. (This is not currently planned.)

Many of the SatCom congestion problems result from inadequate management. For example, it is strongly suspected by the JCS J-6 office that many band-width hungry, high-speed data circuits users could accomplish their missions utilizing much lower data-rate circuits. Many single channel UHF satellite channels circuits support only one user on a wide-band 25 KHz channel. The Drug Enforcement Agency has recently become a large user of satellite communications, but their management of assets and assessment of requirements are still considered inadequate (8).

Management of communication satellite assets is specified in JCS Memorandum of Policy-178 which gives overall management responsibilities to the JCS. The J-6 Division of the JCS is tasked with administering this allocation. All routine requests for satellite connectivity must be approved and validated by the JCS before installation. Discrete blocks of satellite channels may be allocated to the separate unified and specified commands for their own validation and management in special situations. This method of managing requirements ensures that a mission-critical circuit will be implemented if the mission is of sufficiently high priority. However, due to the high demands for satellite circuits, a circuit that has been approved and validated for installation will very likely mean that another subscriber of lower priority will lose service (32).

As a management tool, the Defense Communications Agency maintains a list of pre-validated satellite circuits/networks for its principal users, called a User Requirement Database (9). The J-6 Division of the JCS uses this document as the primary means of routinely allocating satellite communications assets (25).

In terms of hardware, the scarcity of available satellite channels is now due more to the lack of usable frequencies and power restrictions on the satellite than to a lack of communications satellites. Both the UHF and SHF frequency spectrums have become so crowded that increasing the number of satellites for a geographic area is becoming academic. The very limited power of the satellite transpon-

ders has also denied the use of satellite communications to subscribers on numerous occasions.

SOLUTIONS TO THE SHORTFALL

We have discussed the current links utilizing satellite communication and the capabilities of our current and planned systems. We have also identified the areas where deficiencies exist--either in number or capabilities. We can summarize major problem areas as follows:

1. Not enough channels (Satellite transponders)
2. Not enough frequencies in the UHF spectrum
3. Not enough power on the satellites
4. Big/Expensive terminals
5. Expensive satellites (spacecraft + launch cost)
6. Civilian lease costs and incompatible terminals
7. Poor coverage near polar regions.

We now move to the question: "What can we do about these deficiencies?" In short, how can we overcome the SatCom shortfall?

No single panacea will answer this question. An analogy borrowed from computer science says demand will always grow to exceed capacity by 10%. That is, no matter how many satellite channels are available and no matter what their capabilities, we will always want more and better. Nevertheless, we offer some possible solutions to the SatCom shortfall. While no single solution solves all shortfalls, a combination of several measures can greatly expand our present capabilities without exhausting the shrinking funds

available in today's defense budget.

REALLOCATION

One obvious answer to SatCom congestion is to take satellite links away from those who can communicate adequately via other paths or who don't need as many channels as they control. This sounds simple but is probably infeasable. The reasons seemingly redundant links are now on satellites are often more political than operational. Most satellite links are allocated by and to senior officers who may be unaware of alternative paths or who may simply enjoy the prestige of a dedicated SatCom link.

Most senior officers would be perfectly willing to give up a superfluous net or a satellite channel if they were shown another unit's more pressing need, but few staff officers have the courage to confront them with the issue. Satellites are not the only source of dependable long-haul links, but most senior commanders immediately equate "long-haul" to "SatCom." It is most likely that inertia will keep current satellite links as they are until users and allocators are educated about alternatives and are convinced of their quality.

In another type of reallocation, strategic users should be encouraged to move from UHF satellites to less crowded SHF satellites. For many users this will only be feasable when smaller SHF terminals and small, high-gain, SHF antennas are widely available.

TIMESHARING

More realistic than wholesale reallocation is a simple, relatively low-budget solution: timesharing. In basic terms, timesharing involves more than one user sharing the same satellite channel at the same time. This can be done in several ways and with low or high sophistication. We have already discussed one form of timesharing--DAMA--which is included in the LEASAT satellites.

The simplest form of timesharing involves dividing each unit of time into a number of "slices" and giving each user who shares the channel a "piece" of the time period. This concept is called timeslicing or time-division multiplexing and is widely used in computers which service several users simultaneously.

Using computer timeslicing as a model, the military has already started employing this concept widely for data communications. Again, we refer to the example of LEASAT's DAMA circuitry. DAMA is being used for digital voice as well as for data, but the concept can still be greatly expanded. With the data rates of today's satellite channels, dozens of digital voice communications can be multiplexed without any noticeable degradation in quality. (Note that on UHF SatCom frequency-division DAMA which requires more bandwidth is not a viable option for reducing congestion since bandwidth--well as channels--are already in short supply.)

A variation on the timeslicing theme would greatly expand the number of users on a single channel. We call

this variant our "Headline News" model. CNN Headline News divides its program into a series of segments, one each for headlines, financial news, weather, sports, etc. During routine periods, each department gets a specified number of minutes each half hour. However, during times of breaking news, one department may get a much larger segment than normal. Applying this model to battlefield SatCom links, each hour could be divided into a series of segments and each segment issued to a "bundle" of multiplexed users. For instance, one group would get the top-of-the-hour to ten-minutes-past segment; the next would get ten-minutes-past to twenty-minutes-past, and so forth. The time boundaries would be enforced by switching software.

This system would work best for routine communications. In fact, most information will not suffer from a fifty minute transmission delay. If information is particularly time-sensitive, the "Headline News" method of handling breaking news can be further employed. Those who have critical information would obtain permission to override the system and commandeer additional segments.

A similar, less structured timesharing system can accommodate fewer users, but requires less overhead. In this variation, a group of users would be allowed to share a channel under the assumption that only a certain number of users would be on at any given time. Those who need an override capability to "bump" their way into the circuit would have a prearranged priority similar to the priority/flash/flash-override system used in routine tactical switch-

ing networks. The variation here would be the mechanism used to establish priority for overriding the circuit. Currently, priority is based largely on rank or position. An alternate plan would give any user the capability to enter the channel and if the user limit was exceeded, the user who had been on the longest would be bumped.

Some high-priority users could still be given a "never bump" mark which would keep them from being cut off regardless of the length of their conversation or data transmission. The advantage of this system over priority-override systems currently in use is the capability for any user to enter the system at any time. In order for our proposed system to be tolerable, the total number of potential users would have to be closely controlled to insure a relatively small percentage of users are "bumped." This system is similar in concept to the system in place on some of the AFSATCOM SHF systems.

SURROGATE SATELLITES

A potentially more costly solution to the satellite shortage than timeslicing involves the use of surrogate satellites. These surrogates are transponders flown at relatively high altitudes which look exactly like satellites to ground terminals. True satellites are needed for very long distance links, but high altitude surrogates can meet the needs of those links of up to several hundred miles. Users who would benefit from SatCom, but who do not require very long distance communication fall into two broad cate-

gories: those who are hampered by terrain limitations and those who simply need the high quality of SatCom links. Surrogate satellites can potentially reduce congestion on true satellites by providing a tactical commander with his own satellite to move about the battlefield at will. Surrogates are also cheap (compared to true satellites), yet provide SatCom quality. Finally, surrogates provide equally good service at the poles--an area poorly serviced by geo-stationary satellites.

Surrogate satellites come in various sizes and channel capacities. (See Table VI for various models and their characteristics). These surrogates can be mounted in various vehicles including remotely piloted vehicles (RPV), manned aircraft, and high altitude balloons. Each platform has advantages and disadvantages.

Table VI. Surrogate satellite characteristics

Model Name	Channels	Frequency	Power	Host	Range
Zephyr	1	UHF	10W	Balloon	440 NM
RT-460(A)	4	UHF	10W	Various	400 NM
Lockheed M & S	1	UHF	10W	RPV	400 NM

RPVs are mobile, and enemy fire poses no risk to their "pilot"--the ground operator. However, they are altitude limited and are not able to carry a large payload. Manned aircraft, such as a C-130 have tremendous payload capacity and are also mobile, but using such a carrier for hosting a surrogate satellite risks its crew and a valuable aircraft

which could be performing other important missions. Both manned and unmanned aircraft are limited by fuel and the endurance of their crew (or operators). Although in-flight refueling is available for some aircraft, crew replacement is infeasable; while operators can be rotated on RPVs, the aircraft can not be refueled in the air. The Joint UAV office in cooperation with the Army Signal Corps is working to develop a high-altitude UAV which could fly at 70,000 feet and loiter for weeks on station. (13)

Another limitation of air-breathing aircraft is altitude. The higher a surrogate satellite is flown, the greater its range. Some applications may not require great range, but terrain limitations are best overcome by creating the greatest angle possible between transponder and ground terminal.

Unmanned balloons create no risk to a crew and can be flown at great altitudes, thus extending the possible range between terminals by increasing the angle between terminal and transponder. However, balloons also have disadvantages. They must be tethered to the ground and thus require constant minding. Also, the longer the tether, the more the the position of the balloon (and its surrogate satellite) will vary. This variance is due to unpredictable wind currents. A last disadvantage is the hazard a long tether presents to friendly aircraft. See Figure 9 for the relationship of surrogate altitude to transmission distance.

SURROGATE SATELLITE PLATFORMS VS RANGE

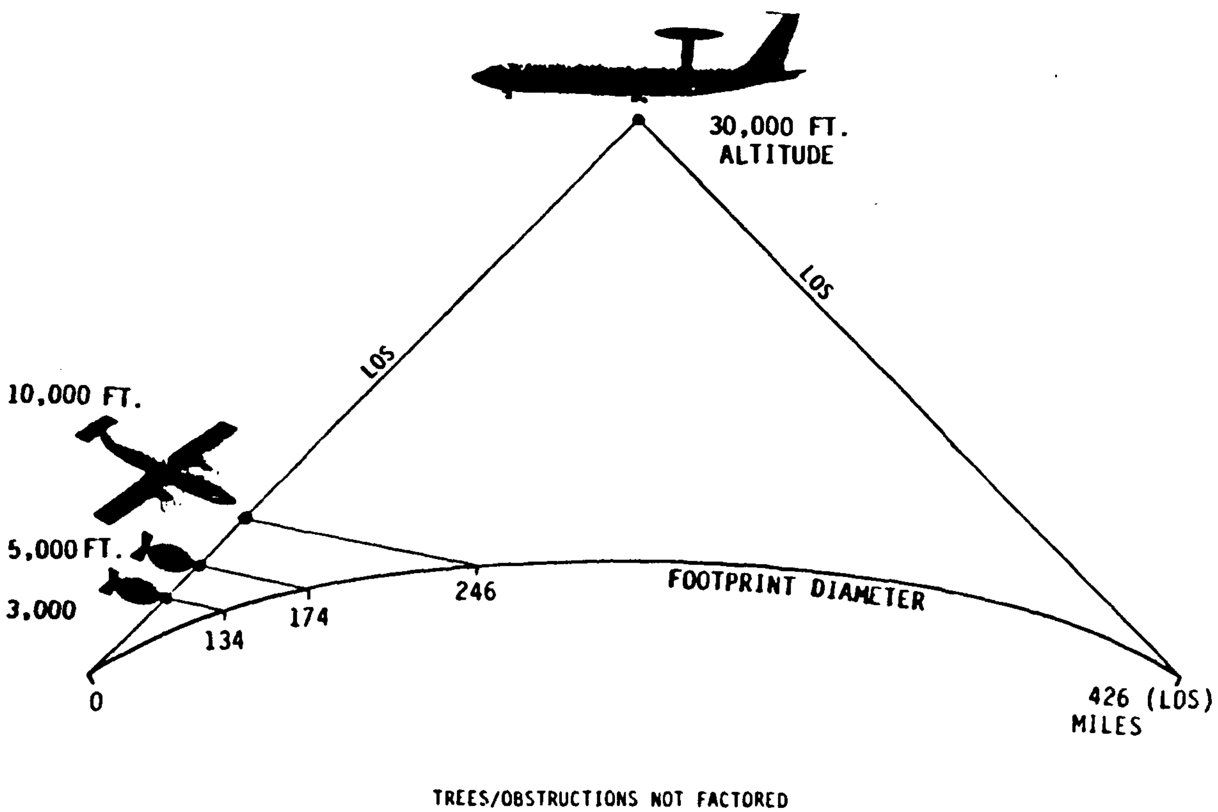
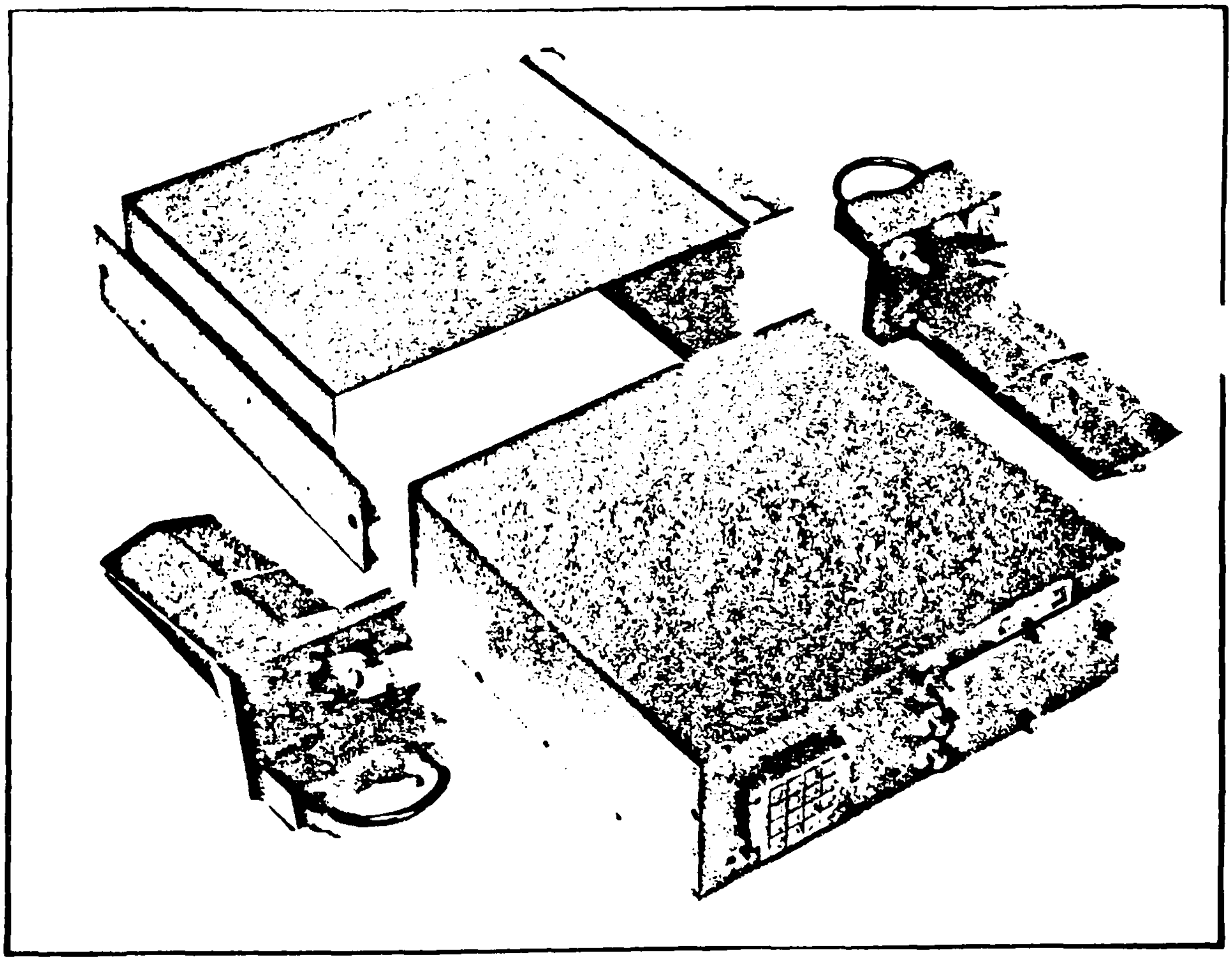


FIGURE 9

No single combination of surrogate satellite and host equals a true communication satellite's capabilities. Still, surrogates are much cheaper to build and operate, and easier to move about in their "orbits" than true satellites. Surrogates may be the answer in situations when an actual satellite may not be available or is only needed for a limited time.

The Army, Navy, and Marine Corps are already testing surrogate satellites such as the DARPA-U.S. Navy "Zephyr" program (16:14) and Cincinnati Electronics' RT-460(A) (26:1). The RT-460(A) (Figure 10) has already seen action with operational forces, and a limited number of units are being ordered by Army and Marine commands for further field testing.

SURROGATE SATELLITE UHF RELAY



RT-460(A)

FIGURE 10.

COMMERCIAL SATELLITES

Another solution to the satellite shortage is already being pursued--the large-scale utilization of commercial satellites for military operations. Commercial satellites are abundant, and the capabilities of many of the large telecommunication satellites rival the best of the current military satellites. However, several drawbacks are hindering the rapid exploitation of civilian satellites.

The first, and most difficult, problem to overcome is the sheer cost of leasing channels on commercial satellites. According to COMSAT (14), prices from commercial vendors for SHF links similar to those needed for Desert Shield communication would exceed $5000 per month for a standard 64 Kb voice/data channel plus $100,000 to purchase a ground terminal. Costs would run as high as $9000/month for a video channel plus $200,000 in terminal and compression equipment. These prices are constant regardless of time of day or how little that channel is actually used.

Another drawback involves the positioning of the satellites. Most are in orbits such that their foot prints focus either on the U.S. and Western Europe or on the U.S. and Eastern Asia--major centers of population and finance. Civilian firms are not in the business of moving their satellites to please a military user, regardless of the justification, since other customers would be thrown into chaos. Furthermore, civilian satellites have little to no crypto and are easily jammed. Evidence of this vulnerability is the infamous "Captain Midnight" episode when a pirate over-

whelmed and replaced an HBO cable television broadcast.

However, the biggest single item hampering the exploitation of commercial satellite resources by the military is the military's lack of compatible ground station terminals. Military ground terminals will not work with most of the current commercial satellites. Additionally, the satellite ground stations which the companies own are neither conveniently located (for military users), nor mobile, nor cheap to lease. Additionally, the terminals are easy targets for terrorist attack since they are not in particularly secure locations.

"CIVIL RESERVE SATELLITE FLEET"

Is there a better way to utilize commercial satellite resources? One possible answer we propose in this paper is a variation on the Civil Reserve Air Fleet (CRAF) which has proven so successful in the massive airlift to the Middle East. For lack of a better name, we refer to our proposed system as the Civil Reserve Satellite Fleet (CRSF).

The CRSF program would entail a cooperative development program between the civilian telecommunications industry and the Department of Defense. The military would subsidize a portion of the cost of each satellite and would take permanent leases on some number of channels. DoD would allow the firm to offer the rest of the channels on the open market.

In return for this compensation, the commercial firm would build in certain features necessary to the military user (such as EMP hardening, crypto, jam-resistance, and

compatibility with current DoD ground stations and terminals). The company would also provide a below-market lease rate on the DoD channels, agree to a mutually beneficial orbit, and include a provision for the government to "commandeer" a number of additional channels in time of national emergency.

There are obvious similarities between our CRSF program and the CRAF program. Under CRAF, DoD pays civilian airlines to modify their cargo aircraft with reinforced decks and wide doors. In times of national emergency, when the CRAF is activated, DoD requires the companies to divert planes to military use. Similarly, our proposed CRSF program would require commercial firms to include DoD-specific hardware and to provide extra channels to the military on short notice. Unlike the CRAF, which is activated only in time of national emergency, a portion of the CRSF program would be "activated" at all times.

The CRSF idea has advantages over current uses of civilian satellites, such as the LEASAT program, in which the Navy leases commercial satellites for the life of the satellite. LEASAT satellites are outdated and do not have many of the features DoD now needs. DoD also uses commercial satellites by taking ad-hoc, short term leases on satellite channels. But in doing so, the military is subject to exorbitant prices and has little if any control over the satellite orbits or their foot prints.

The CRSF would give DoD the freedom to pay reasonable rates for only what it needs, while guaranteeing the inclu-

sion of features necessary for effective command and control of today's forces.

Before the CRSF program could be implemented, the question of administrative responsibility would have to be settled. There are several alternatives. The individual services could each run separate programs, but this would dilute the "buying power" of DoD and would invite redundancy and inefficiency. A better choice would be to have a single agency run the entire CRSF program. Likely candidates include AFSPACECOM, USSPACECOM, and Defense Communications Agency. AFSPACECOM, which already controls the majority of defense satellites, would be the most logical choice for coordinating the CRSF program.

The costs for such a CRSF program include development, administration, and channel leases. Additionally, the military would have to share technology with the commercial firms in order to have them accommodate hardware or software peculiar to military needs. Still, these costs should be less than the ad hoc leasing of commercial circuits and would provide much more reliability and capability over the long term.

NON-SATELLITE TECHNOLOGIES

Finally, other non-satellite technologies may provide effective alternatives to satellite communications. Some are still experimental while others have been around since radio was an infant. We will mention three alternatives which offer significant promise.

1. HF Radio: HF radio still provides cheap, effective long-haul communications in many situations. In the rush to advance satellite technology, HF radio has been allocated little R&D money. However, advancements in ionosphere tracking and improvements in transmission and reception efficiency would make HF a much more acceptable choice for many military applications. Recent R&D efforts have produced some dramatic improvements such as the low-cost, whip-tilt antenna adapter which dramatically enhances HF radio's near-vertical incident skywave capability.

Regardless of advances, HF has inherent limitations in the number of possible channels and its low data rate. The limitation in available channels is due simply to the narrow 2-30 MHz frequency range which can satisfy only a fraction of the users needing quality long-haul communications. HF can be improved, but it will still be increasingly relegated to back-up status in the future.

2. Fiber Optics: Fiber optic cables are starting to be seen more and more in field applications. Fiber optic cables offer superb quality and impressive bandwidth, and are not susceptible to interference from outside sources (such as power cables). Likewise, they are impossible to monitor without physically tapping the cable.

Of course, fiber optics will never meet the long-haul requirements that SatCom satisfies. Fiber optics can, however, offer significant capabilities for relatively short links which currently need SatCom because of requirements for very high quality, high data rates, and freedom from

outside interference.

3. Meteor Burst Communication (MBC): MBC is already seeing limited operational use. It is a technology in which high-power VHF is bounced off the ionized trail of meteors entering the upper atmosphere. In general, a transmitter waits for a meteor to enter the atmosphere at a specific point in the sky. Once a meteor appears in this area, a burst transmission is quickly bounced off the ionized meteor's trail. (See Figure 11.) Because of the vast number of meteors which daily enter Earth's atmosphere, this technique can be used reliably anywhere in the world, 24 hours a day. MBC can theoretically cover distances of up to 2000 kilometers and routinely spans 1500 kilometers in operational use. Additionally, MBC works well in polar regions and is actually enhanced in a nuclear environment.

One of the key advantages of MBC is its low probability of intercept. MBC transmission will strike the earth in an elipse approximately 10 x 40 kilometers in area. This means that not only is the signal very hard to intercept, stations who are more than 65 kilometers apart can use the same transmission frequencies. (20:9) In the early days of the technology, MBC terminals were the size of large filing cabinets. However, low-power terminals weighing under seven pounds are now being fielded. (12:143) (See Figure 12 for leading MBC terminals.)

MBC has many drawbacks, though. Chief among them is the low data rate. Because of the short life of a meteor trail (typically less than a second), limited amounts of

METEOR REGION

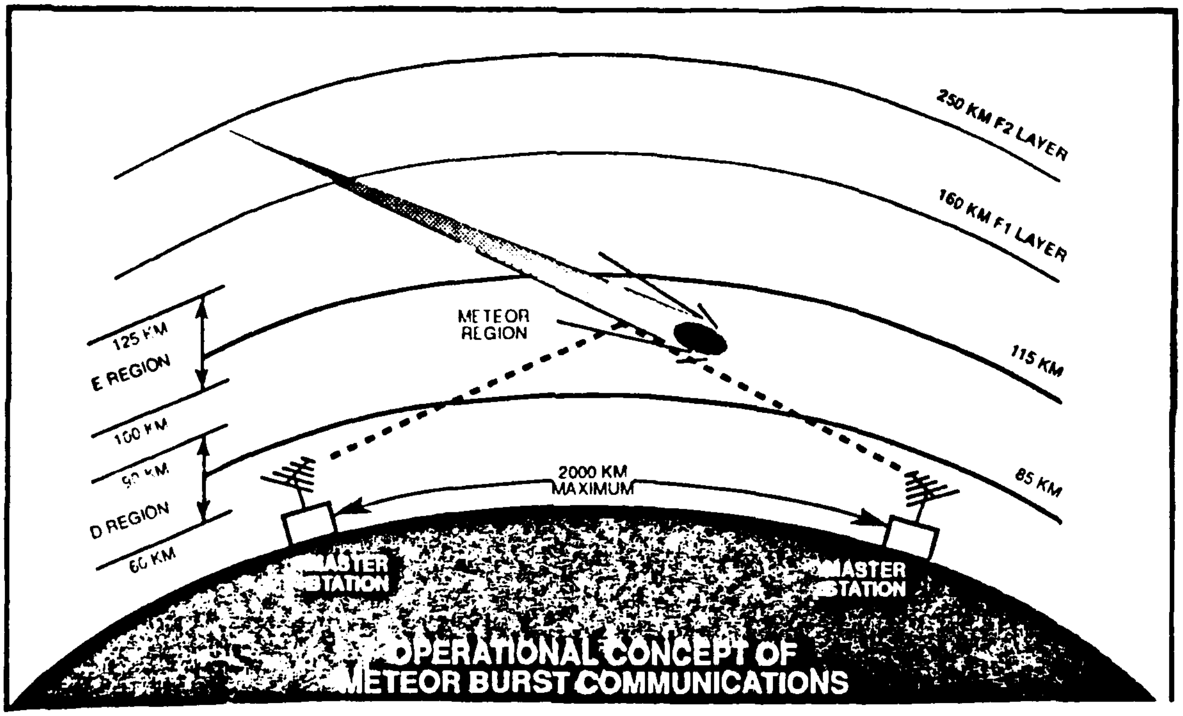
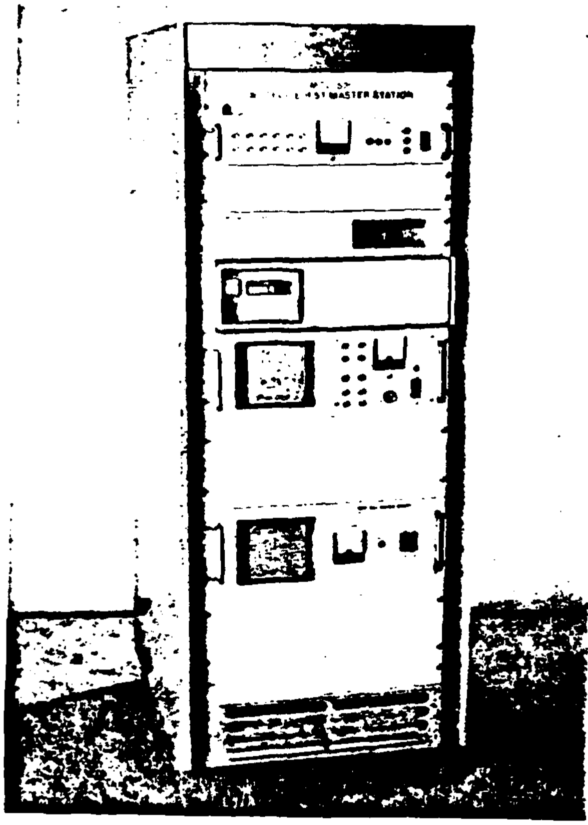


FIGURE 11

METEOR BURST TERMINALS

MCC 520 MCC 550 B



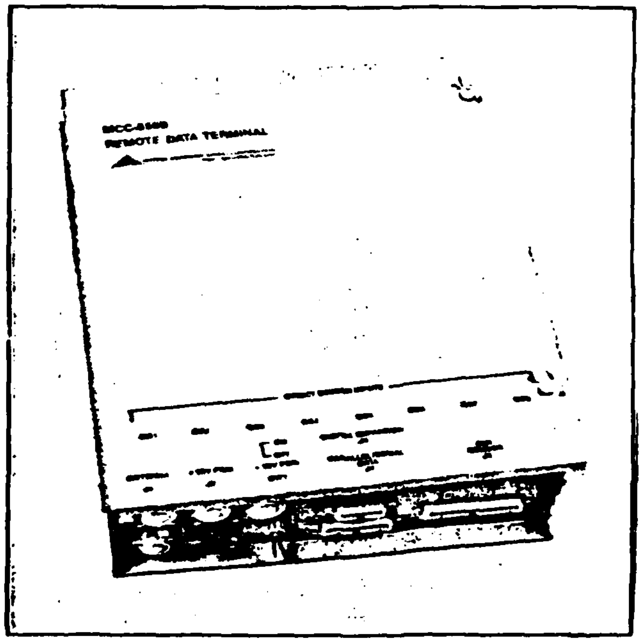


FIGURE 12.

information may be sent in any single burst. When averaged over a long period of steady transmission, full duplex transmission rates fall in the 75-600 bits per second range. As computer technology improves, data rates are certain to increase, but transmission will always be much slower than that provided by satellite communication.

Another limitation of MBC transmitters is the power they require. Early base station MBC transmitters required one to ten kilowatts of power. The latest versions are much smaller, but master stations still require as much as 400 watts. Finally, because MBC uses burst transmission, it does not support voice communications.

CONCLUSIONS

It probably comes as no surprise to the reader that requirements for SatCom exceed available resources. A variety of units within a Joint Task Force would benefit greatly from SatCom or its equivalent if it were available. SatCom users may not necessarily be interested in its long-haul capabilities. Their overriding concern may instead be high quality, high data rates, or freedom from terrain limitations.

Current UHF satellites are full to capacity. SHF satellites are approaching capacity as well, and demand continues to grow. New military satellite systems such as MILSTAR or LightSat will provide considerable capabilities once they are fielded, but projections place their initial operational dates years in the future, if funding is not cut

altogether. Even if these systems are fielded and meet every expectation, some users will still have inadequate satellite access. The satellites currently in orbit are aging and will eventually be lost to dependable use. In any event, some "lower echelon" units will additionally be kept out of the system by higher priority users.

As a result of this combination of factors, alternatives to SatCom should be aggressively pursued. We have covered timesharing as a way of extending existing satellite capacity as well as several technological alternatives to SatCom which are currently being tested or are in limited use. Many of these have advantages over SatCom--not the least of which is lower cost. We have also suggested a Civil Reserve Satellite Fleet program as a way to add satellite surge capacity without bearing the everyday costs of additional satellites.

No single solution will answer all needs for additional high-quality, high-volume C4I2 needs of today's force. The most likely answer to the SatCom shortfall is a combination of innovative techniques spanning the high-technology of meteor-burst communication to the relatively low-technology of surrogate satellites and improved HF radio. Better channel management and more judicious allocation is also a necessity. Finally, we must find a better way to lease commercial satellites for long-term and contingency operations. The CRSF program described above is a first step and would likely prove as useful for C4I2 as the CRAF program has for military airlift.

Do we have enough space-borne assets to meet expected Joint Task Force C4I2 needs? The answer is surely no, but we can correct the shortfalls if we act now, work aggressively, and take advantage of the type of innovation which launched the space program in the first place.

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